

FESTUCA ALOHA AND *F. MOLOKAIENSIS* (POACEAE: LOLIINAE),
TWO NEW SPECIES FROM HAWAII

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ABSTRACT

Festuca aloha, sp. nov. of Kaua'i and **F. molokaiensis**, sp. nov. from Moloka'i are described and illustrated. The two species are endemic to the Hawaiian archipelago and grow on steep mountain slopes and volcanic cliffs with other native mesic flora. A key to the species of *Festuca* found in the Hawaiian Islands is given.

KEY WORDS: *Festuca*, new species, Hawaii, Loliinae, key

RESUMEN

Se describen e ilustran **Festuca aloha**, sp. nov. de Kaua'i y **F. molokaiensis**, sp. nov. de Moloka'i. Las dos especies son endémicas del archipiélago de Hawaii y crecen en acantilados volcánicos y en laderas montañosas pendientes junto con otra flora autóctona de ambientes mésicos. Se proporciona una clave de identificación de las especies de *Festuca* que habitan en las islas del archipiélago.

While revising specimens of *Festuca* deposited at the United States National Herbarium (US) the first author found two specimens of fine-leaved individuals from Kaua'i that were identified as *F. rubra* L. However, these individuals exhibit several characters that separate them from holarctic red fescues of the *F. rubra* complex, including: leaf blades flat with involute margins, sheaths open, relatively long ligules, and ovaries with densely hairy apices. After reviewing specimens of *Festuca* from Molokai'i deposited at the Bishop Museum (BISH) we noticed an additional taxon. Previously, the only species of *Festuca* and relatives recorded from Hawai'i and the Pacific include the endemic, *F. hawaiiensis* Hitchc. (Hitchcock 1922), a robust broad-leaved species placed in *F.* subg. *Drymanthele* V.I. Krecz. & Bobrov sect. *Banksia* E.B. Alexeev (Alexeev 1980), and three Eurasian species: the fine-leaved *F. rubra* L. (*F.* subg. *Festuca* sect. *Aulaxyper* Dumort.); and the broad-leaved *F. arundinacea* Schreb. and *F. pratensis* Huds. [*F.* subg. *Schedonorus* (P. Beauv.) Peterm. sect. *Schedonorus* (P. Beauv.) Endl]. The taxonomy of *Festuca* s.l., the largest genus of monophyletic subtribe Loliinae Dumort., is in a state of flux. Much additional research is needed to properly align the taxa, although preliminary data from DNA sequencing (Catalán et al. 2007; Inda et al. 2008) suggest that two major clades may exist. As elements of the "broad-leaved" clade, the latter two species have been classified within the separate genus *Schedonorus* P. Beauv., as *Schedonorus arundinaceus* (Schreb.) Dumort and *S. pratensis* (Huds.) P. Beauv. (Soreng et al. 2003; Snow 2008). In addition, *Festuca* subg. *Drymanthele* is sometimes recognized as the genus *Drymochloa* Holub. The "fine-leaved" clade of fescues, including *F. rubra*, are placed in *Festuca* s.s. (Soreng et al. 2003). However, results are still equivocal concerning the resolution of the division at the base of the two major clades.

Specimens were examined from the Bishop Museum (BISH), National Tropical Botanic Garden (PTBG), Missouri Botanical Garden (MO), and the United States National Herbarium (US).

Festuca aloha Catalán, Soreng & P.M. Peterson, sp. nov. (Figs. 1A–J, 2). TYPE: U.S.A. HAWAII: KAUA'I, Hanalei district, Kalalau Rim, Kalalau side below and W of the first Kalalau lookout, isolated hanging side-valley of lowland diverse mesic forest surrounded by precipitous cliffs, associated with species of *Gouania*, *Peucedanum*, *Poa mannii*, *Hedyotis*, *Lysimachia glutinosa*, *Melicope pallida*, *Nototrichium*, *Dubautia*, *Dryopteris*, *Metrosideros*, *Lipochaeta subcordata*, *Lobelia niihauensis*, *Lipidium*, *Nestegis*, *Hibiscus kokio*, *Eragrostis*, *Santalum*, *Myrsine*, *Acacia*, and *Psychotris*, 790 m, 13 Mar 1992, K.R. Wood 1701 & S. Perlman (HOLOTYPE: PTBG-17679; ISOTYPE: US-3252239).

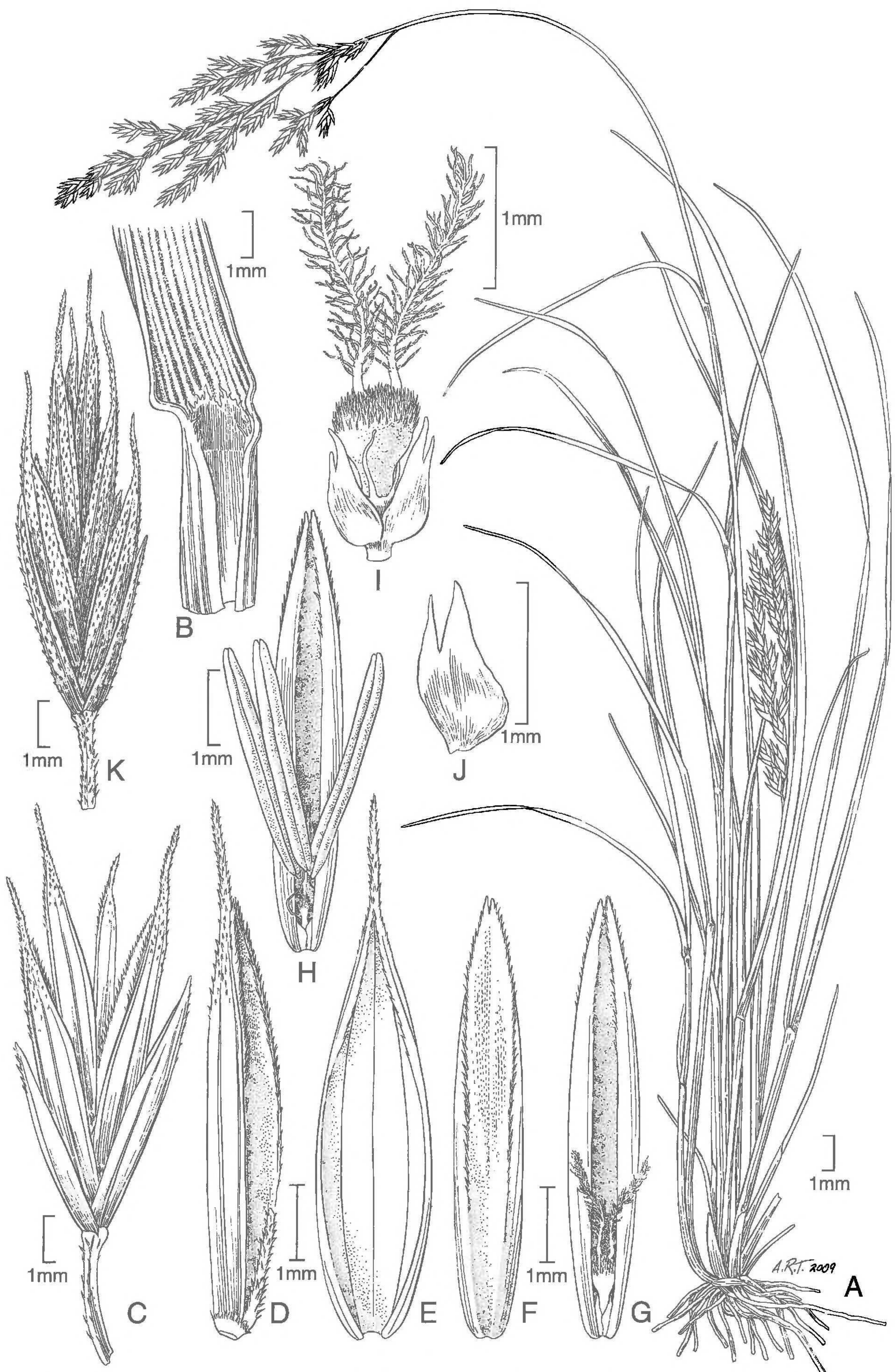


FIG. 1. Illustration of *Festuca aloha* Catalán, Soreng & P.M. Peterson (isotype, US-3252239). A. Habit. B. Sheath, ligule, and blade. C. Spikelet. D. Floret with rachilla. E. Lemma, ventral view. F. Palea, dorsal view. G. Palea with ovary, ventral view. H. Palea with immature ovary and mature stamens, ventral view. I. Lodicules, mature ovary, and basal remnant of filaments. J. Lodicule. *Festuca molokaiensis* Soreng, P.M. Peterson & Catalán (holotype, BISH-728771). K. Spikelet.

A *Festuca hawaiiensis* Hitchc. paniculis 8–11 cm longis, angustibus, ramis erectis, ascendentibus; pedicellis (1–)1.5–3.5(–5) mm longis; lemmatibus 5.8–8 mm longis; laminis 1.5–2.4 mm longis, recedit.

Plants perennial, caespitose, with extravaginal innovations; cataphylls conspicuous, brownish. **Culms** 45–70 cm tall, erect, slender (ca. 1 mm diam.), nodes 2–3, smooth and glabrous. **Leaf sheath** margins fused for 1–2 mm at base, overlapping more than ½ the length below, sparsely villose abaxially when young, becoming glabrous at maturity, purple-brownish at the base, greenish above, becoming fibrous in age at base; **auricles** absent; collars glabrous; **ligules** 1–1.5 mm long, scarious, glabrous, brownish, apex obtuse, dentate-erose; **leaf blades of vegetative shoots** 22–33 cm × (1–)1.5–1.7 mm, erect to pendant, flat with involute margins, glabrous and smooth abaxially, hirsute along protruding ribs adaxially, the hairs up to 0.1 mm long, cross section (Fig. 2) about 1 mm bearing 13–16(–20) larger vascular traces or veins, each with prominent ribs adaxially alternating with smaller ribs on the secondary and tertiary veins, **sclerenchyma** strands forming trabeculae or girders on most veins; **leaf blades of culms** about 22 cm × 2.4 mm, erect to pendant. **Panicles** 8–11 × 2.5–4 cm, erect, axis and peduncle smooth; loosely contracted with 34–66 spikelets, spikelets mostly at branch tips; panicle branches 2(3) per node, basal branches 4–6 cm and ca. 1/2 the length of panicle, angled, erect or ascending, smooth proximally to scabrous, angled distally. **Spikelets** 8.2–13 mm × 3.5–6.0 mm, 4–6-flowered, broadly lanceolate, pale green, sometimes tinged with purple; pedicels (1–)1.5–3.5(–5) mm long; rachilla internodes 0.8–1.2 mm long, scabrous; **glumes** lanceolate, green, margins very narrowly scarious (<0.5 mm), apex acute; **lower glumes** (3.6–)3.9–4.2(–4.5) mm long, 1-veined; **upper glumes** 5.2–5.5(–6.0) mm long, 3-veined; **lemmas** 5.8–8.0 mm long, 5-veined, glabrous below, scabrous near the apex, green or tinged with purple at the apex, mucronate to awned, the mucro or awn 0.5–1.1 mm long, scabrous; callus rounded, obliquely angled (to 45°), smooth to dorsally minutely scabrous at the apex; **paleas** longer or shorter than lemma, scabrous on and between keels; stamens 3, **anthers** 3.1–4.2 mm long; **ovary** densely hairy on upper 1/3. **Caryopsis** not seen.

Additional material examined. **U.S.A. Hawai'i. Kaua'i:** Hanalei district, Kalalau Rim, N of Kahuamaa flat, 990–1020 m, 3 Mar 1991, K.R. Wood 631, M. Query, S. Montgomery (PTBG-9498); north aspect, 1060–1190 m, 5 Apr 1991, K.R. Wood 901 & M. Query (PTBG-13876); Kalalau side below and W of the first Kalalau lookout, 13 Mar 1992, K.R. Wood 1704 & S. Perlman (PTBG-17678, topotype); Honopu Rim, undisturbed cliffs, rare, with old inflorescence, growing in clumps, seen with *Panicum lineale*, 2800 ft, 6 Nov 1993, K.R. Wood 2832 (PTBG-29690; MO-4639044); Kalalau valley, Clumping on N facing basalt cliffs, seen with *Poa mannii*, *Panicum lineale*, *Eragrostis variabilis*, *Carex meyenii*, ca. 3000 ft, 17 Jun 1994, K.R. Wood 3245 (PTBG-20438); Pohakuao, hanging valley between Kalalau and Hanakoa, below Puu Ki and Kaaalahine Ridge, 2000 ft, 4 Jan 1992, K.R. Wood 1761, S. Perlman & J. Lau (BISH-621133, PTBG-12875, US-3250261); Waimea district, with *Panicum lineale* and *P. beecheyi*, 2000 ft, 30 Mar 1993, K.R. Wood 2470, & S. Perlman (PTBG-18788), K.R. Wood 2471 & S. Perlman (PTBG-18779); Awaawapuhi valley, N facing slopes above stream, 0.5 mi along trail, growing with *Wilkesia gymoxiphium* and *Lipidium serra*, 3300–3500 ft, 18 May 1994, K.R. Wood 3193, S. Perlman & M. Hartley (PTBG-15270); Upper Kawaiiki: Kaluahaulu Ridge (Mohihi-Waiialae trail), W of trail along with swept rim, drop into drainage, *Acacia koa*–*Metrosideros polymorpha* mixed mesic forest with *Dubautia laevigata*, *Dianella sandwicensis*, *Poa sandwicensis*, *Schiedea stellarioides*, *Peperonia macraeana*, and *Claoxylon sandwicense*, 1149 m, 14 Nov 1996, K.R. Wood 7605 (PTBG-42661).

Comments.—*Festuca aloha* has panicles 8–11 cm long, narrow, branches erect and ascending; lemmas 5.8–8 mm long; and leaf blades 1.5–2.4 mm wide; in contrast *F. hawaiiensis* has panicles 30–40 cm long, widely open, branches patent or patent-erect; lemmas 9 mm long; and leaf blades 2–3 mm wide.

The illustrator Alice Tangerini noticed that all florets with mature anthers of *F. aloha* contained small, undeveloped ovaries (Fig. 1H). Mature ovaries with well-developed styles were found only in florets that had already shed their anthers (filaments were still present) [Fig. 1I]. Therefore, *F. aloha* is apparently protandrous.

Etymology.—The specific epithet *F. aloha* name derives from the Kalalau mountains of Kaua'i.

Conservation status.—*Festuca aloha* has been found in at least six different localities of Kauaii, covering a distribution area of approximately 700 km². The number of individuals varies among populations but usually there are less than 1000 individuals per population. Based on these preliminary data, the new species clearly falls within Vulnerable (VU) category as defined by the IUCN (2001). The major threats to individuals of *F. aloha* are the allochthonous plants, such as: *Cyperus meyenianus* Kunth, *Erigeron* sp., *Kalanchoe pinnata* (Lam.) Pers., *Lantana camara* L., *Melia* sp., *Passiflora mollissima* (Kunth) L.H. Bailey, *Rubus*

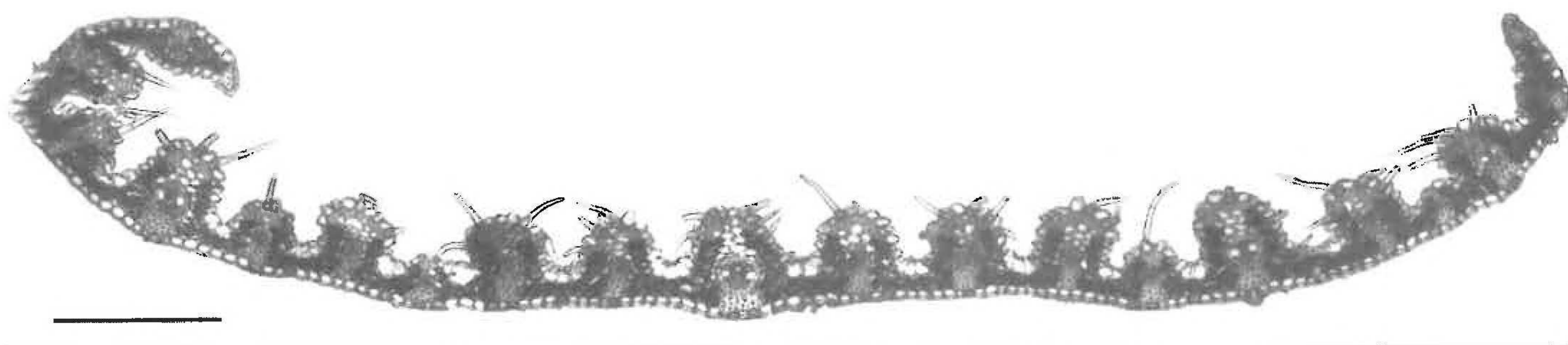


FIG. 2. Leaf blade cross section of vegetative shoots of *Festuca aloha* Catalán, Soreng & P.M. Peterson (US-3252239). Scale bar = 0.1 mm.

rosifolius Sm. ex Baker, *Setaria gracilis* Kunth, *Triumfetta* sp.; and goats and pigs (K.R. Wood, on herbarium label).

Festuca molokaiensis Soreng, P.M. Peterson & Catalán, sp. nov. (Fig. 1K). TYPE: U.S.A. HAWAII. MOLOKA'I: Kupaia Gulch, on steep slopes in mesic forest, occasional, associated vegetation: *Metrosideros*, *Coprosma*, *Leptecophylla*, *Dodonaea*, *Alyxia*, *Viola*, *Melicope*, *Myrsine*, *Diospyros*, *Dryopteris*, *Phyllanthus*, *Luzula*, *Selaginella*, and *Carex*, 21.1 19564 N 156.936999 W, 880 m, 3 Apr 2007, H.L. Oppenheimer H40704, S. Perlman & N. Tangalin (HOLOTYPE: BISH-728771).

A *Festuca aloha* Catalán, Soreng & P.M. Peterson, paniculis et spiculis magis gracilis et scabris, lemmatibus omnino scabris, arista longiori 1.5–2.8 mm, antheris brevioribus 2–3 mm, glumis inferis (5.0–)5.2–5.5(–5.7) mm, glumis superis (6.0–)6.2–6.8(–7.0) mm, differt.

Plants perennial, cespitose, with extravaginal innovations; cataphylls conspicuous, brownish. **Culms** up to 60–70 cm tall, scabrous below panicle. **Leaf sheaths** with margins fused for 1–2 mm at base, overlapping more than ½ the length below, purple-brownish at the base, greenish above, becoming fibrous at base in age; **auricles** absent; collars glabrous; **ligules** 1.5–2.5 mm long, scarious, glabrous, brownish, apex obtuse, dentate-erose; **leaf blades of vegetative shoots** approximately 34 cm × 2 mm, more or less pendant, flat with involute margins, glabrous and smooth abaxially, hirsute along protruding ribs adaxially and on margins and apex, dull green, cross section similar to that of *F. aloha*, about 2 mm wide bearing 25 larger vascular traces or veins, each with prominent ribs adaxially alternating with smaller ribs on the secondary and tertiary veins, bulliform cells between adaxial ribs, **sclerenchyma** strands present forming trabeculae or girders on most veins, sclerenchyma strands with thin cell walls (adaxially) and thick cell walls (abaxially); **leaf blades of culms** about 21 cm × 2 mm, flat with involute margins, densely scabrous adaxially. **Panicles** 8.5–13 × 4 cm, loosely contracted with approximately 75 spikelets, spikelets located at the ends of the branches, 3(4) branches on basal node, 2(3) branches in other nodes, axis and branches strongly scabrous; basal branches as long as 7 cm, more than 1/2 the length of the panicle, angled, suberect to ascending. **Spikelets** 7–9 × 3–4 mm, 5–6-flowered, broadly lanceolate, pale green; pedicels (2–) 4(–9) mm long; rachilla internodes scabrous; **glumes** lanceolate, green, margins very narrow, scarious, apex acute; **lower glumes** (5.0–)5.2–5.5(–5.7) mm long, 1-veined; **upper glumes** (6.0–)6.2–6.8(–7.0) mm long, 3-veined; **lemmas** (5.0–)5.5–6.0 mm long, 5-veined, scabrous dorsally and near apex, green, awn 1.5–2.5 mm long, scabrous; callus rounded, obliquely angled (to 45°), scabrous; **paleas** slightly shorter than lemma, bidentate at apex, keels scabrous, between keels scabrous; stamens 3, **anthers** 2.8–3.0 mm long; **ovary** densely hairy on upper 1/3. **Caryopsis** not seen.

Comments.—*Festuca molokaiensis* differs from *F. aloha* by having more delicate and thinner, more numerous and lax branches; scabrous panicles and spikelets; lemmas scabrous throughout, awns longer 1.5–2.8 mm; anthers shorter 2–3 mm; lower glumes (5.0–)5.2–5.5(–5.7) mm; and upper glumes (6.0–)6.2–6.8(–7.0) mm. In comparison to *F. aloha*, culms are scabrous on the nodes; panicles 8.5–13 cm long, more delicate, axis and peduncles scabrous, branches densely scabrous, angled; spikelets more delicate; rachilla more slender; lower glumes (5.0–)5.2–5.5(–5.7) mm long; upper glumes (6.0–)6.2–6.8(–7.0) mm long; lemmas 5–6 mm long, evenly scabrous across the back from the base to the apex, 3-veined or infrequently faintly 5-veined (lateral veins obsolete or obscure), awned, the awn 1.5–2.8 mm long; and anthers 2–3 mm long.

Etymology.—The specific epithet of *F. molokaiensis* derives from the island of Moloka'i.

Conservation status.—*Festuca molokaiensis* is only known from the type locality where it has been recorded as occasional (Oppenheimer, on herbarium label). Due to the scarcity of available data on the potential distribution, demography, and population status of *F. molokaiensis*, we consider to be a Data Deficient (DD) taxon (IUCN 2001).

TAXONOMY AND PHYLOGENY

Festuca aloha and *F. molokaiensis* are morphologically similar to the Hawaiian endemic, *F. hawaiiensis* in ligule size and shape, ovary hairiness, and leaf-blade anatomy (Hitchcock 1922). However, *F. hawaiiensis* is a more robust plant up to 150 cm tall with longer (30–40 cm) and wider panicles that are open with 3–5 spreading and drooping branches at the nodes, and larger lemmas up to 9 mm long. *Festuca hawaiiensis* grows at higher elevations, at ca. 2000 m, in rich soil on moist wooded hills on the island of Hawaii.

Festuca aloha and *F. molokaiensis* resemble the western North American, *F. californica* ssp. *hitchcockiana* (E.B. Alexeev) Darbysh. [Darbyshire & Pavlick 2007] in leaf blade cross section, panicle features, and hairy ovary apices. However, *F. californica* ssp. *hitchcockiana* differs from the new species by having a more robust and cespitose habit, possession of a continuous sclerenchyma layer on the abaxial side of the leaf blade, a partially hairy collar, and longer ligules with ciliate apices.

The new *Festuca* taxa also show similarities with Macaronesian volcanic cliff dwellers: *F. agustinii* Linding., *F. jubata* Lowe, and *F. francoi* Fern.Prieto, C. Aguiar, E. Días & M.I. Gut. (Saint-Yves 1922; Fernández Prieto et al. 2008) because all share extravaginal innovations and flat to inrolled (or conduplicate) leaf-blades with some complete sclerenchyma trabeculae. However, the latter species all differ from the new species by having glabrous ovary apices and short (< 1.5 mm) ligules.

We analyzed the ITS and *trnL-F* sequences of two samples of *Festuca aloha* from different populations from Kauai [*F. aloha* 1: Kalalau, US-3252239 (isotype), GenBank GQ162205 (ITS) and GQ162208 (*trnL-F*) accessions; *F. aloha* 2: Pohakuao, US-3250261, GenBank GQ162206 (ITS) and GQ162209 (*trnL-F*) accessions] and one sample of *F. molokaiensis* from the only known population from Molokai [*F. molokaiensis* 1: Kupai Gulch, BISH-728771 (holotype), GenBank GQ162207 (ITS) and GQ162210 (*trnL-F*) accessions]. We then conducted heuristic parsimony analyses for the combined ITS and *trnL-F* dataset (10,000 random entry trees, TBR, mulpars off, saving no more than 10 trees of length <10 per replicate; 1000 bootstrap replicates with the same parameters as in the original search) using these three samples and combined them with our previous data for *Festuca* on a worldwide level (Catalán et al. 2007; Inda et al. 2008).

All three samples grouped together within the broad-leaved *Festuca* clade (Fig. 3), nested within the well supported clade *Subulatae* + *Leucopoa* p.p. [92% bootstrap (BS)], which were separated from *F. californica*, *F. rubra*, and the Macaronesian *Festuca* sect. *Aulaxyper* s.l. species. *Festuca aloha* was monophyletic (99% BS) and sister to *F. molokaiensis* (98% BS).

The two *F. aloha* specimens from different populations on Kauai (*F. aloha* 1 & *F. aloha* 2) had similar sequences (99% BS; 1 *trnL-F* nucleotide substitution difference); however, the sample of *F. molokaiensis* from Molokai showed several nucleotide differences in both the ITS (five substitutions) and *trnL-F* (two substitutions) regions with respect to *F. aloha*. These molecular differences also support the taxonomic separation of the two species. Despite the limited infraspecific sampling, the ITS variation found between *F. aloha* and *F. molokaiensis*, from the same Hawaiian archipelago, is remarkable as these species show more nucleotide differentiation than that found between other closely related species [e.g. the Pyrenean *F. eskia* Ramond ex DC., and *F. gautieri* (Hack.) K. Richt. with only two ITS nucleotide substitutions], and between species from different Macaronesian archipelagos (e.g., Madeiran *F. jubata* and Azorean *F. petraea* Guthn. ex Seub. with three ITS nucleotide substitutions). Unfortunately, *F. hawaiiensis* could not be included in the molecular analysis because it is extremely rare and we have no material other than the type.

The closest relative of *F. aloha* and *F. molokaiensis* in our analyses (Fig. 3) was the eastern Asian *F. parvigluma* Steud. (88% BS), followed by the northwestern North American *F. subulata* Trin. (77% BS), both belonging to *F.* subg. *Subulatae*, and then by the Siberian–North American *F. altaica* Trin. (92% BS), placed

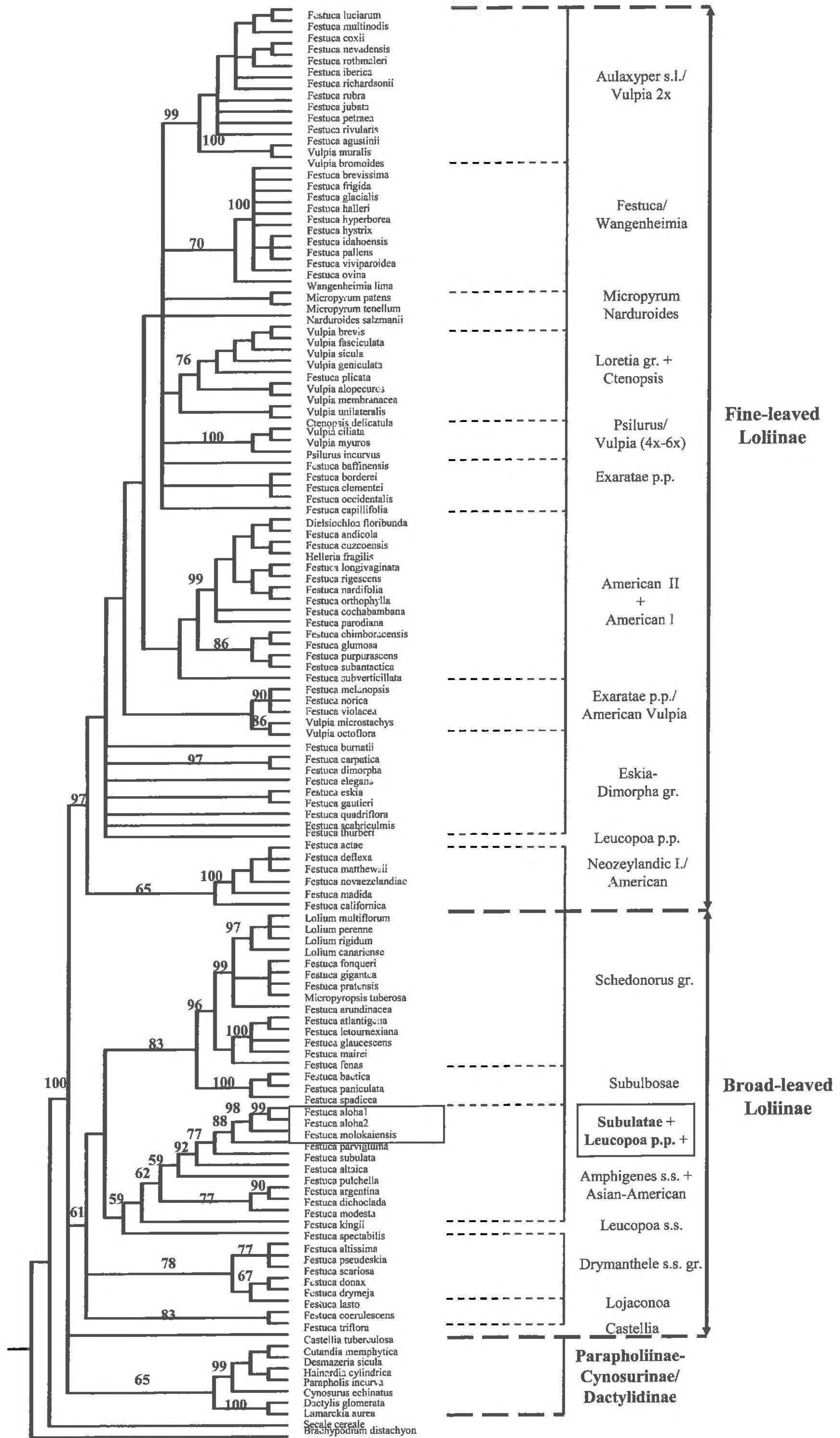


FIG. 3. Strict consensus tree of 805 most parsimonious Loliinae trees (tree length 2105; consistency index excluding uninformative characters 0.400; retention index 0.762) based on combined ITS/*trnL-F* data showing the phylogenetic placement of *Festuca aloha* Catalán, Soreng & P.M. Peterson and *F. molokaiensis* Soreng, P.M. Peterson & Catalán. Bootstrap support values are indicated on branches.

within *F.* subg. *Leucopoa* sect. *Breviaristatae*. In a separate ITS strict consensus tree the *F. aloha*/*F. molokaiensis* clade fell within the broad-leaved clade, and was closely related to the Asian *F. parvigluma* and *F. modesta* Steud. [sometimes treated as *Drymochloa modesta* (Nees ex Steud.) Holub]. In contrast to the ITS data, a *trnL-F* strict consensus tree placed *F. aloha*/*F. molokaiensis* in a polytomy at the base of the fine-leaved clade, among fine-leaved taxa and taxa intermediate between fine- and broad-leaved forms of *Festuca*.

Given the different resolutions between separate nuclear and plastid DNA sequence topologies for our species, it is possible that *F. aloha* and *F. molokaiensis* are of allopolyploid origin. On morphological grounds *F. aloha*, *F. molokaiensis*, and *F. hawaiiensis* are all part of the same complex, representing a common pattern of morphological speciation in upland habitats of different islands along the Hawaiian archipelago.

KEY TO THE SPECIES OF *FESTUCA* IN HAWAII

1. Lower leaf blades with auricles; leaf blades usually 5–12 mm wide, flat.
 2. Auricles ciliate on margin; lemmas awned (awn 2–3 mm), more or less scabrous distally _____ ***Festuca arundinacea***
 2. Auricles not ciliate on margin; lemmas muticous, smooth or only sparsely scabrous distally _____ ***Festuca pratensis***
1. All leaf blades without auricles; leaf blades 0.3–5 mm wide, involute to flat but when flat the margins involute.
 3. Ligules 0.1–0.5 mm long; ovary apices glabrous; leaf blades conduplicate; leaf sheaths usually closed below (open < ¼ their length); leaf blades of vegetative shoots in cross section without sclerenchyma girders. _____ ***Festuca rubra***
 3. Ligules 1–2.5 mm long; ovary apices densely hairy; leaf blades flat with involute margins; leaf sheaths generally open ½ their length [they are fused only for 1–2 mm at the base]; leaf blades of vegetative shoots in cross section with sclerenchyma girders.
 4. Panicles 30–40 cm long, open, the branches spreading or drooping; leaf blades 3–5 mm wide; known only from Hawaii _____ ***Festuca hawaiiensis***
 4. Panicles 3.5–25 cm long, usually narrow, the branches patent, erect or ascending; leaf blades 0.3–2.4 mm wide.
 5. Lemmas scabrous only in the upper third, intermediate veins distinct, awns 0.5–1 mm long; anthers 3.1–4.2 mm long; ligules 1–1.5 mm long; lower glumes (3.6–)3.9–4.2(–4.5) mm long; upper glumes 5.2–5.5(–6.0) mm long; known only from Kaua'i _____ ***Festuca aloha***
 5. Lemmas evenly scabrous throughout, intermediate veins absent or obscure, awns 1.5–2.8 mm; anthers 2–3 mm long; ligules 1.5–2.5 mm long; lower glumes (5.0–)5.2–5.5(–5.7) mm long; upper glumes (6.0–)6.2–6.8(–7.0) mm long; known only from Moloka'i _____ ***Festuca molokaiensis***

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